Latest Achievements in Gunfire Detection Systems

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ABSTRACT

For more than fifteen years, 01dB-METRAVIB has been carrying out many research and development activities in battlefield acoustics. In this article, we present our latest achievements in the particular domain of Gunfire Detection Systems (GDS). These systems are essentially based on acoustic detection with specific signal processing of ShockWaves and Muzzle Blasts. Their purpose is to detect and locate sniper and small-arms fire. The main parameters, which are estimated by these systems, are azimuth, elevation and range of the origin of a shot.

These classical acoustic sensors can also be associated with other sensors, such as optical systems, thermal cameras, and LASER systems, etc. The latest on-going developments in 01dB-METRAVIB Gunfire Detection Systems are the following:

- *New systems with more than two acoustic arrays,*
- *Specific data fusion and battlefield-oriented displays,*
- *New wireless systems with radio devices,*
- *New systems coupled with daylight and/or thermal cameras ("PIVOT"),*
- *Original system allowing for specific detection mode ("Bullet Detector"),*
- *Other associated sensors.*

After a short overview of state of the art systems performances, we present these new systems with a particular emphasis on their technical specifications and their interests, both in today's battlefield and in law enforcement operations.

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1.0 INTRODUCTION

01dB-Metravib relies on all its knowledge to detect and localize potential or real threat for security reasons using acoustics and vibration techniques.

Boosted by a 1995 French requirement regarding the “sniper valley” during the Bosnian conflict in Sarajevo, the company has mainly focused on the detection of small caliber gunshots. In the same time, the company drove several research programs, such as SYMSATI and DITIREMB, mixing acoustics, optronics and LASER technology. More recently, the DAOTE development program was dedicated to acoustic (and multi-sensor) wireless technology and the ARTEMIS and CELACANTE studies have allowed for many progresses in gunshot signal simulation and reduction of false alarm rates, respectively. We must also mention developments in the artillery domain with ALADIN, LACTA and PILARCANON. All these programs were supported by the French DGA.

Our company is now a worldwide leader in this area. To fulfill the customer’s needs, 01dB-Metravib has developed complementary know-how, to enlarge the features of the core systems by integrating optics and robotics state of art devices.

Combat-proven, PILARw has been used by many Armed and Security Forces around the globe. Current customers range from the US Special Forces (USSOCOM) in the West to the Australian Defense Forces (ADF) in the East, including Europe, Land, Kosovo, East Timor, Macedonia, all major UN peacekeeping endeavors have been sustained by PILARw deployment.

2.0 OVERVIEW OF “PILAR” AND CLASSICAL PERFORMANCES

Based on its expertise in acoustics and signal processing, 01dB-Metravib has developed monitoring systems for the detection and localization of battlefield threats.

PILARw system is an acoustic Gunfire Detection Systems (GDS) device dedicated to detection, localization of small-arms fire. It is composed by one (or two) acoustic arrays with embedded microphones and electronics, a compact signal processing unit and a laptop unit for the display of results. It is declined in two configurations:

- Ground based
- Vehicle mounted

2.1 Ground version

Using two Acoustic Sensors Arrays, PILAR MKII-w system not only locates the origin of the shot in 3D, but also displays the bullet trajectory.

The PILAR MKII-w device locates the origin of the shot within ±2° in bearing and a typical ±20% in range depending on the distance between the two arrays versus the firing range. The detection range can be over 1000 m.

2.2 Vehicle version

The vehicle-mounted system uses the same sensor array as the ground-based system, but with a specific mounting. PILAR MK-IIw is designed to provide situation awareness on stationary and moving wheeled vehicle at a speed up to 45km/h.

The PILAR MK-IIw system locates in 3D the origin of the shot within ±2° in bearing when stationary, ±5° when in motion, a typical ±50m in range for small to medium distances and ±100m for longer range.

PILAR MK-IIw is a stand-alone device that can be easily plugged (RS232) to existing onboard systems, such as digital mapping, navigation system or mission planning.

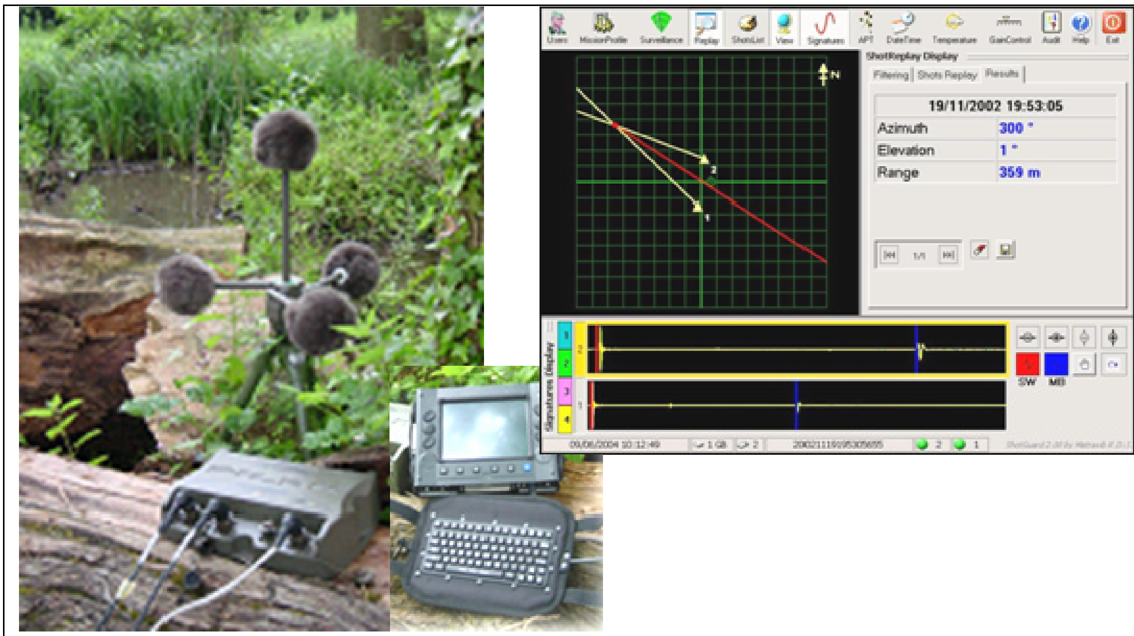


Figure 1: PILARw system and IHM in ground version

2.3 Exploitation of acoustic waves of a gunshot

When a shot is fired from a small arm, two distinct acoustic waves are generated: the muzzle blast (MB) and the shock wave (SW).

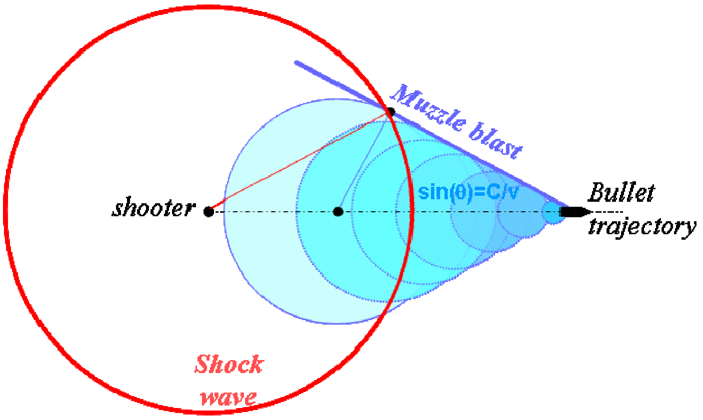
The MB is coming from pressure depletion at the muzzle of the weapon. It is a nearly spherical wave that propagates in all directions and can be characterized as a low frequency acoustic wave (typically below 500 Hz).

The SW is created in a cone shape when the bullet is traveling at supersonic speed. The cone shape may be illustrated by the result of acoustics monopole distribution (which propagates in a free field) along the bullet trajectory. It is characterized by an N-shaped acoustic signature and exhibits high-frequency wave (typically in the 1 kHz to 4 kHz band).

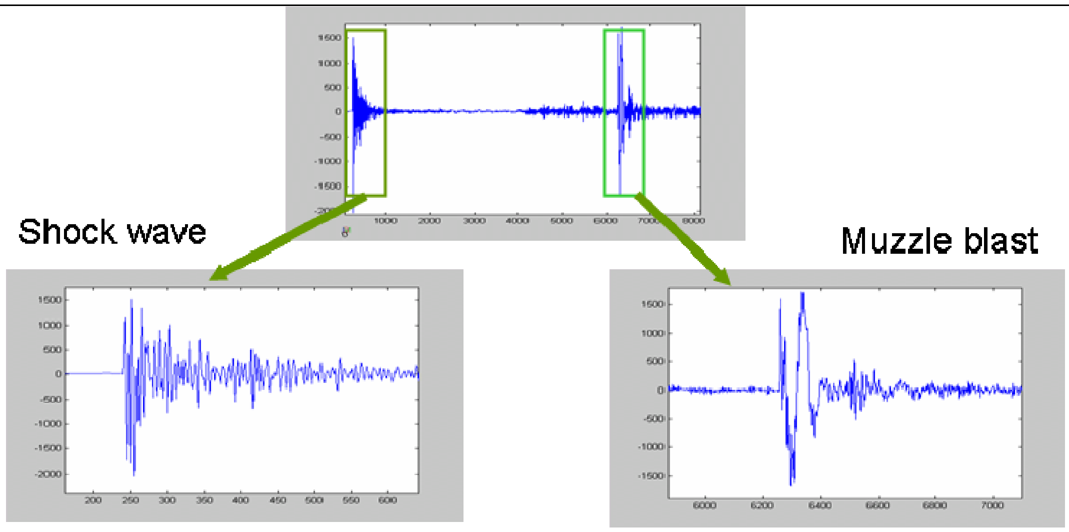
The propagation speed of the muzzle blast (sound propagation speed) is less than the supersonic speed of the bullet. In the time domain, the first acoustic wave observed is the shock wave that allows for gunshot detection.

With a single array, measuring acoustic signature on each microphone, the Time Of Arrival (TOA) and the Direction Of Arrival (DOA) are estimated for SW and MB. Then, the muzzle blast wave front alone allows determining the azimuth of fire location. By measuring the difference of TOA between MB and SW and using the DOA of the two wave's front it is possible to estimate the distance to the shooter. The shock wave alone does not give a precise direction and presents an ambiguity on the direction: two possible directions of the shot are possible. For this reason, it is recommended to use two acoustics arrays to extract useful location information from the shock wave only.

With two arrays, it is then possible to estimate the bullet trajectory and the bullet speed and to increase the origins precision of the shot localization (see § 4).



Physique model of propagation



The first wave is the Shock Wave, followed by the Muzzle Blast

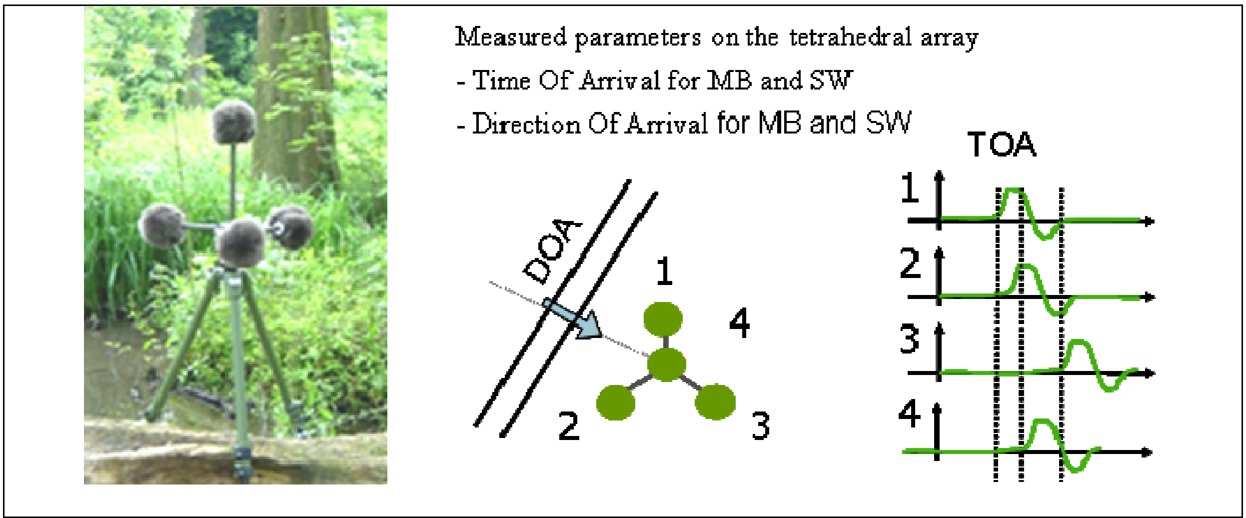


Figure 2: Acoustic signature generated by small caliber gunfire and measurements

2.4 Performances

	Type of detected wave		
	MB only	SW only	SW and MB
One array	Azimuth Elevation	Two possible angle sector origins of the shot (2)	Azimuth Elevation Distance to the shooter (1)
Two arrays	Azimuth Elevation Distance to the shooter	Azimuth Elevation Bullet trajectory (2)	Azimuth Elevation Distance to the shooter Bullet trajectory (2)

(1) for supersonic shot with a bullet trajectory close to the array (from 30 m to 50 m)
(2) for supersonic shot with a bullet trajectory between the two arrays

Table 1: Acoustic of shooter parameters estimated with PILAR

Azimuth	+- 2°
Elevation	+- 5°
Range	+- 10% up to 200m +- 20% up to 600 m +- 30% up to 1200m
Detection range	> 1000 m (environment-dependent but above effective range of the weapon)
Detected calibers	5.56 mm to 25 mm

Table 2: Summary of PILAR performances using 2 arrays (standard elevation)

3.0 PRESENTATION OF NEW MULTI-ARRAYS SYSTEMS

These developments are integrated as part of the DAOTE ("Détection Acousto-Optronique de Tireurs embusqués") program [6]. From our most recent R&D efforts, we have designed a full detection system using more than two acoustics arrays, all connected with proper wireless technology. This extension of the PILAR system constitutes a key development to enlarge application to a wide survey zone and to increase performances (detection and threat localization) by means of data fusion.

3.1 A system with three arrays

The Radio Acoustic PILAR GDS (RAGDS) is composed of three identical sets of acoustic macro-sensors (DIAM and Acoustic Array), and by a set of acoustic concentrators (SMART and a central PC). RAGDS can operate on external battery, which makes it an autonomous system.

Each acoustic macro-sensor makes up a beacon: it contains a tetrahedral array with a positioning and a communication module (EASY box), a tripod and a DIAM module. The EASY box contains a GPS under dome, a compass under lower dome, a temperature sensor (*) under dome and a radio antenna. The DIAM module ensures local array processing (detection and localization for each detected wave front) then transmits results of localization (RLA) to the concentrator. The concentrator performs homogeneous fusion of all RLA coming from each acoustic beacon.

The Radio Acoustic PILAR Gunfire Detection System allows:

- to measure on the three acoustic macro-sensors (acoustic array), the acoustic wave field coming from a gunshot (Shock Wave and Muzzle Blast),
- to measure and to record the GPS position for each acoustic array,
- to measure and to record the orientation for each acoustic array,
- to measure the ambient temperature (*) for each acoustic array,
- to date for each recorded event,
- to transmit all this information to the central PC.

(*) *The temperature is an input parameter for the array processing.*

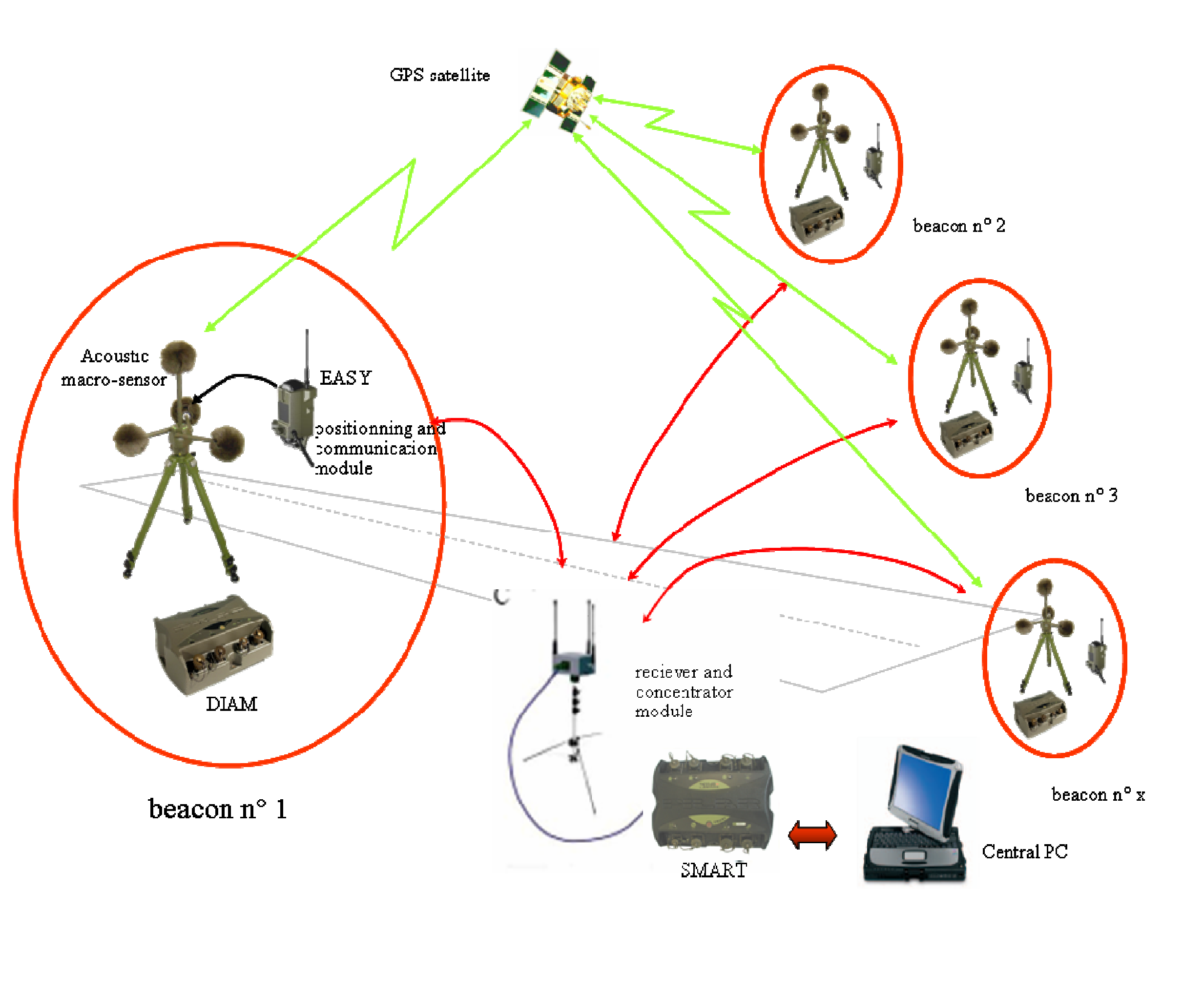


Figure 3: New system with more than two acoustic arrays

3.2 A wireless technology

Wireless communication using radio frequency is the new technology chosen by 01dB-Metravib to ensure data transmission between each beacon and the concentrator module. This technique presents many advantages: fast installation, no cables, free communications.

The radio communication (performed by the EASY module) is based upon a frequency band ranging from 869.40 MHz to 869.65 MHz. These bands are part of the frequency band called ISM (Industrial, Scientific and Medical). Three frequency bands can be used: 869.4 MHz, 869.525 MHz, and 869.65 MHz. The use of these frequency bands is free of charge. No user license is necessary. The radio modem emission power used to transfer the data (RLA) is limited to 500 mW. Recent measurements about the transmission distance showed that it can be possible to transmit up to 1000 m in the country and in open area. Other frequencies can be integrated depending on end-user requirement.

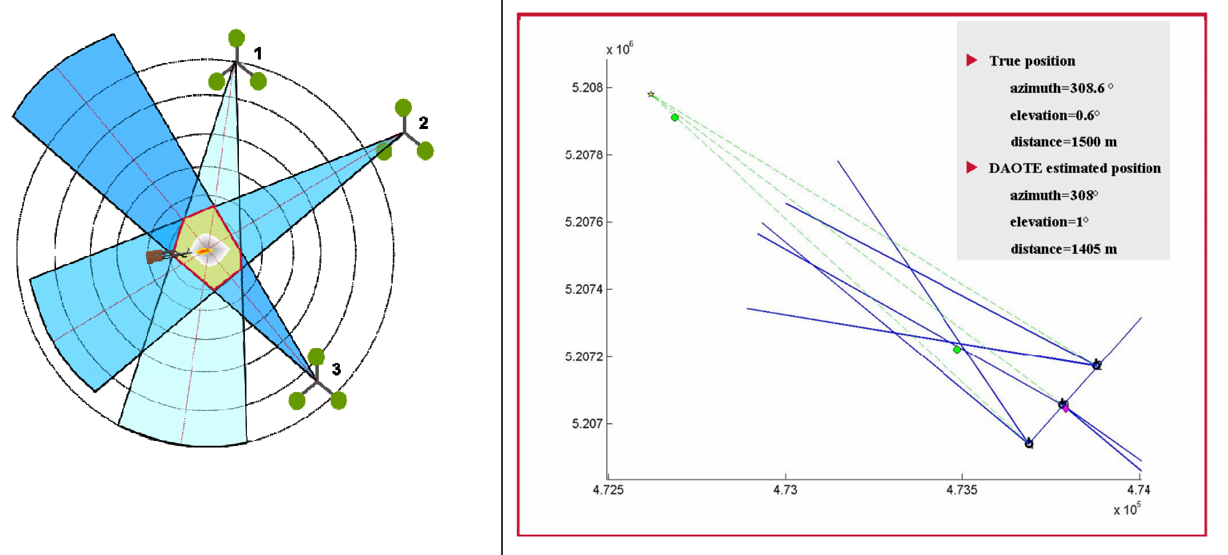
4.0 DATA FUSION

Data fusion processing had been developed with several acoustic arrays to increase detection and localization performance in comparison to a single array. As seen in § 2, the capabilities of PILAR depend of the detected waves and on the number of arrays. The following table summarizes data fusion based on two and three acoustics arrays.

	PILAR output		
Type of detected waves	With one array	With two arrays	With three arrays
SW only	Ambiguous shot origin direction: two possible azimuths. No information on elevation and distance	Shot origin localization (azimuth, elevation and distance), bullet trajectory and bullet speed if travelling between the two arrays	Shot origin localization (azimuth, elevation, distance), bullet trajectory and bullet speed if travelling between the two arrays. All with a better precision.
MB only	Shot origin direction (azimuth and elevation). No information on distance	Shot origin localization (azimuth, elevation and distance), via triangulation	Shot origin localization (azimuth, elevation, distance), via triangulation with a better precision.
SW and MB	Shot origin localization (azimuth, elevation and distance), via TOA between SW and MB. (Distance estimation is reliable if the supersonic if the CPA (*) is within a 30 meters of the array). (*) Closest Point of Approach	Shot origin localization (azimuth, elevation and distance), via combination of methods of data fusion from MB and SW information (TOA and error range).	Shot origin localization (azimuth, elevation and distance), via combination of methods of data fusion from MB and SW information (TOA and error range) with a better precision.

Table 3: Summary of PILAR output depending on the number of arrays

With several arrays, data fusion processing applies logic combinatory on the RLA of each array. For each detected wave, a RLA contains: the TOA, the DOA and the error range associated with the DOA estimation. According to the TOA coherence and to the minimum of the error range, data fusion selects the best waves and computes the shot localization.



Triangulation with three arrays

Result with three arrays

Figure 4: Precision increase in shooting localization by using more than to arrays

Data fusion is a key point of the data processing that increases the gunshot localization performance of the PILARw system.

5.0 CAMERA COUPLING AND OTHER ASSOCIATES SENSORS

The **PIVOT** (PIlar Versatile Observation Turret) is a rapid deployable man-portable system composed of a pan-and-tilt turret equipped with a day / dawn camera driven by a control unit with a high-resolution and high-brightness LCD display. **PIVOT** can be used as a stand-alone surveillance system or in combination with PILARw. In the later case, **PIVOT** will rotate and tilt according to the PILARw information in the proper direction to provide an image of the shot origin in real-time.

Portable, and capable of being easily set-up, these systems provide the observers with reliable and efficient means to detect and record fire from small arms, mortars, rockets, RPG. Based on its optional DV-CAM recorder, PIVOT can really take and record pictures of the attackers. Knowing that such a system is in use will also deter deliberate attacks on observers, since the attacker risks being identified and exposed to retaliatory military operations.

5.1 Option 1: pan and tilt turret equipped with a daylight camera

The **daylight camera** is driven by the associate unit control via RS232 link, according to the PILARw localization information of the shot origin. Then optical zoom and focalization is performed to provide image of the shooter or threat. The camera can also used in stand alone to observe a particular zone by the operator.

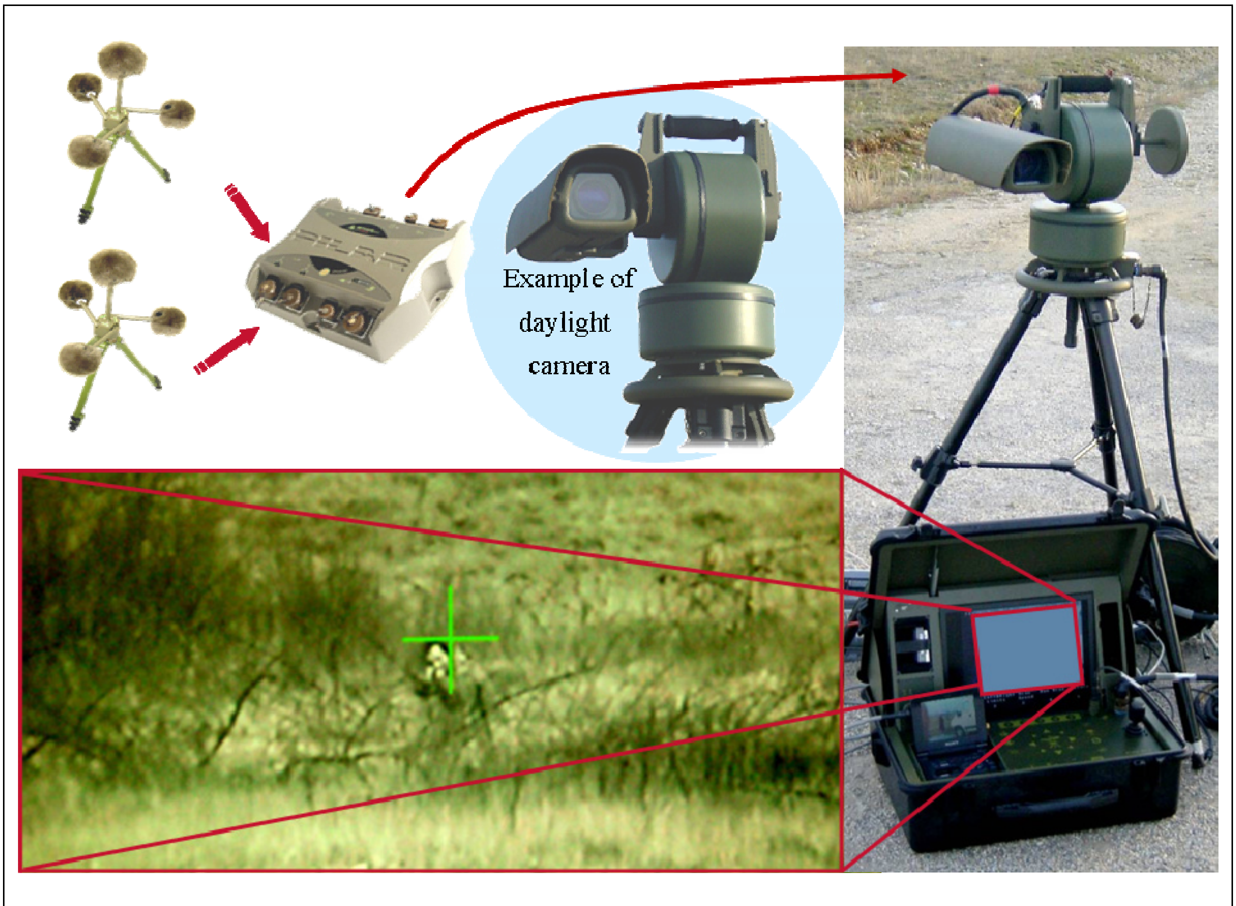


Figure 5: PIVOT system coupled to the PILARw with a daylight camera

5.2 Option 2: pan-and-tilt turret equipped with an infrared camera (IR camera)

The pan-and-tilt turret can also drive an **IR camera** that allows visualization of thermal radiance in the range of few µm (according to the **IR camera**) during the day, as well as during the night. The **IR camera** can also be used in stand-alone mode.

5.3 Other associate sensor

The Acoustic GDS system had been associated to a LASER for sniper detection in the DAOTE program. Acoustic GDS system provides the shot origin while the LASER allows threat detection by ray reflection. Both systems are co localised with a daylight camera and an IR camera for sniper visualisation on an external screen.

The whole system is currently tested by French military services (ETBS) according several criteria: distance, shot angle, gun, calibre, array number.

The Optronic turret associate to the acoustic system for sniper localisation and identification.	

Figure 6: DAOTE system [6]

6.0 THE BULLET DETECTOR

6.1 Concept of employment

The operational feedback of the field PILARw deployments have listed a need for some missions, to limit the triggering of the PILARw only for aggressive shots when the supersonic bullet passing at a distance of less than 50 meters of the deployed PILARw arrays.

In order to meet the operational requirement, 01dB-Metravib has developed the **Bullet Detector** (or HF for High Frequency detector) accessory in order to limit the triggering of PILARw only to aggressive shots: with the supersonic incoming bullet entering the PILARw sensor field and triggering PILARw by the Shock Wave detection only and to reduce the False Alarm rate generated by the background noise.

The **Bullet Detector** requires the latest ShotGuard software version, described below, for its operation.

6.2 Description

The HF detector is an electronic box that processes the acoustic signal from one Array channel and provides a trigger output to the DIAM unit in case the signal shows an aggressive shot (Yes/No). The criterion is based on the high-frequency content of the signal. The second output is only for transferring the raw signal to the DIAM unit for the standard signal processing.

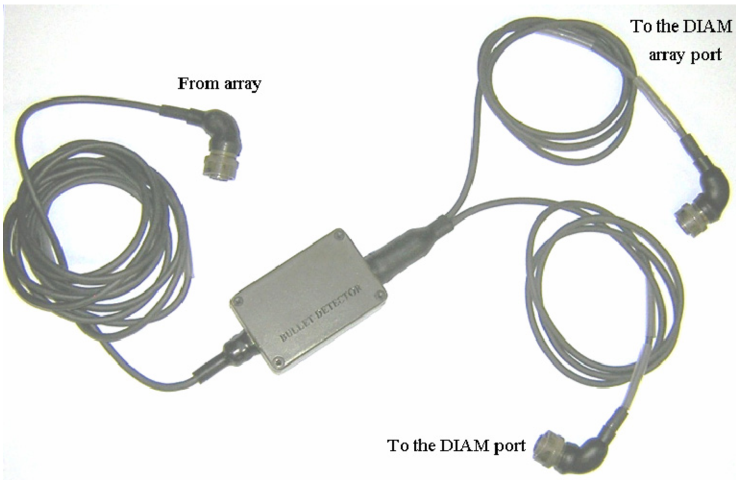


Figure 6: The Bullet Detector

6.3 Shotguard V2 : the new PILARw software

Resulting from 01dB-Metravib continuous R&D investment policy, upgraded versions of the software are periodically available. Among many improvements, ShotGuard software V2 features the following main improvements:

- control of the **Bullet Detector**
- several general improvements, such as:
  - new set-up features (boot screen, Arrays monitoring Zones…),
  - enhanced wave identification (SW and MB) and data fusion algorithms for urban environment.

7.0 CONCLUSION

The GDS program is in constant improvement in relation to the battlefield scenario, to the environment and to the threat nature. The last achievements to the GDS bring best performance in term of localization precision and of false alarm reduction. The GDS performance is particularly improved by the use of more than two arrays offering in the same way the possibility to control a larger area. Data fusion plays a key role in signal processing by SW and MB combination. The GDS false alarm reduction is achieved by the bullet detector and the appropriate data fusion.

On the other hand, the GDS field of application is extended by using camera coupling and other sensors like LASER. Coupled with PIVOT, PILARw becomes a complete observation system, allowing not only threat detection/localization, but also threat recognition.

Acknowledgments

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